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OPTIMIZATION OF PROCESS PARAMETERS FOR PRODUCING HARDENED-GLASS INSULATING PARTS FOR HIGH-VOLTAGE INSULATORS

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The optimization of process parameters and hardening equipment for glass insulator parts that have nonuniform thickness and complex configurations is described. Technical solutions that improved the quality and reliability of insulators are considered.

Hardened glass insulators are currently the most common linear insulators for all voltage classes both for direct and alternating current in most countries. Therefore, optimizing the process parameters and equipment for producing insulators is a topical problem in the context of improving the quality and reliability of insulators.

The processes of batch preparation, glass melting, glass melt feeding, and molding hardened insulation glass particles are similar to the processes in the production of molding glass articles but have stricter requirements on glass melt quality. The heterogeneity of glass registered by the centrifuge method should not be higher than 1.8°C. Heating molded insulator parts, which have different thickness and complex configurations, to the temperature of hardening and cooling is rather difficult with respect to maintaining the geometrical shapes of articles and preventing excessive temperatures and stress gradients in hardening.

For the purpose of developing effective technical solutions to ensure high-quality hardening and reliable service of insulating parts made of low-alkali glass S-14, we determined the dependence of the rate and quality of heating insulator parts on temperature, wavelength of radiant flows from the heaters, and convection flows in the furnace. Furthermore, we investigated the dependence of hardening quality on the cooling conditions and rejection efficiency and the dependence of reliability of insulating parts on thermal control parameters and relaxation of residual stresses in the production of parts.

The hardening parameters for flat glass are sufficiently well studied. We investigated the rate and quality of heating up to the hardening temperature of molded glass articles of varying thickness and complex configurations using samples of sizes $120 \times 35 \times 13$ mm with a thermocouple inserted in the inner layer and insulator parts. Molded samples and insulators parts were placed on special supports at a distance of 100 m inside a continuous electric furnace for heating them to the hardening temperature. The variable parameters in the furnace were the transport grid velocity, the volt-ampere characteristics at the upper and lower heaters across the zones, and the heater spiral section, in order to vary the radiant energy wavelength and efficiency.

The temperature curves inside the furnace were recorded using a thermocouple, and the zones were monitored by potentiometers. The glass surface temperature at the entrance and at the exit from the furnace was monitored by an ITS Izolyator thermometer. The spectral characteristics of glass were analyzed at the Kiev Branch of the VIASM JSC. The deformation of the samples was measured with a IZV-1 instrument and that of the insulator parts was measured with a height gage. The time of articles passing along the furnace zones was measured using a stopwatch.

The tine of staying in the maximum temperature zone for an article was limited by the start of the formation of admissible deformations. This parameter was taken into account in designing molds. The optimum curves for heating insulation parts up to the hardening temperature are indicated in Fig. 1. In this case the preset temperature in the first zones of the furnace is lower than the temperature of the inner layers of a molded thick-walled article, and then it smoothly grows to the optimum hardening temperature for the specified glass composition. Furthermore, the current load on the heaters ensures radiation with a differentiated wavelength along the

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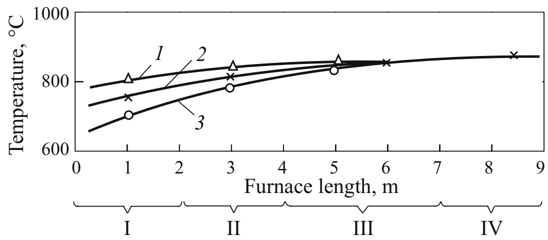

Fig. 1. Curves of heating molded insulator parts made of low-alkali glass S-14 to hardening temperature: *1*) temperatures inside the sample; *2*) temperature inside the furnace; *3*) temperature on the sample surface; I – IV) furnace zones; wavelength (μm): zone I) 5.0 – 4.0, zone II) 4.0 – 3.5, zone III) 2.5 – 2.0, zone IV) 2.0 – 1.5; process duration (min): zone I) 1.5; zone II) 2.0, zone III) 3.5, zone IV) 2.0.

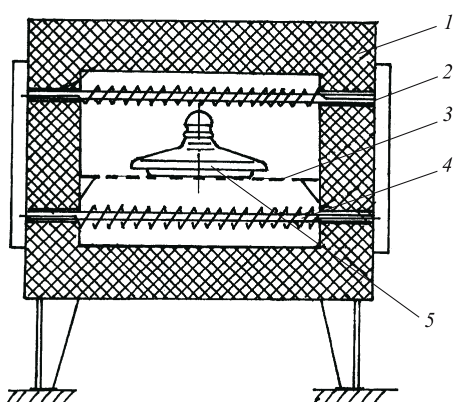

Fig. 2. Design solution for heaters and their layout in the furnace: *1*) furnace; *2*) spiral; *3*) transport grid; *4*) quartz tube; *5*) insulator part.

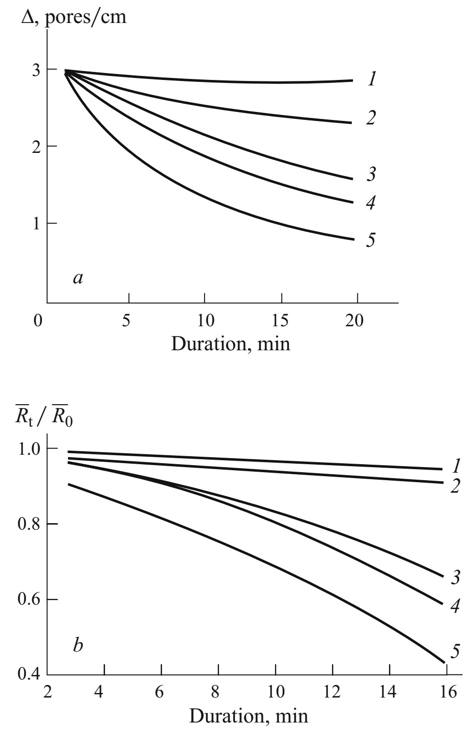

Fig. 3. Time-dependent variations under preset temperatures of 250°C (*1*), 300°C (*2*), 350°C (*3*), 400°C (*4*), and 450°C (*5*) of the degree of hardening (*a*) and mechanical strength (*b*) of samples 13 mm thick of glass S-14 hardened to Δ = 3 pores/cm.

furnace zones. Initially the wavelength of 4 – 5 μm provides for heating the surface of the glass article, which decreases the temperature gradient between the surface and the inner glass layers. The heaters in the furnace are designed to radiate the required energy, which penetrates the glass, is absorbed, and heats the glass across its entire section, which agrees with the data in [1, 2]. This solution prevents the development of current and final temperature gradients across the article and significantly reduces its deformation when heated to the optimum hardening temperature of 870°C. Furthermore, the proposed heater design and the layout of the heaters along the furnace length (Fig. 2) has made it possible to do without fans that create convection flows in the furnace.

TABLE 1

Hardening grids	Air pressure, kPa	Duration, sec
	Cooling stage I	
Upper	8.0 – 10.0	60 – 70
Lower	18.0 – 20.0	60 – 70
	Cooling stage II	
Upper	4.0 – 5.0	300 – 350
Lower	8.5 – 9.5	300 – 350

To harden insulator parts having the configuration of a hollow body of revolution, a hardening grid has been designed (USSR Inventor's Certif. No. 857023) which provides for a more uniform heat removal from the surface of a rotating insulator part, due to the grid ray expanding from its center to its periphery in proportion to the increasing radius and the differentiated diameter of the openings. To obtain more uniform hardening stresses in an article with varying wall thickness, a stepwise cooling schedule has been developed (Table 1). The cooling scheme, which is initially highly intense and then has a lower intensity, significantly improves the homogeneity of hardening stresses in the insulator parts with different thickness. However, it is actually impossible to totally eliminate the presence of local overstresses caused by hardening or by extraneous inclusions in articles with varying thickness.

Therefore, to reject parts that have defects and relaxation of residual stresses, after hardening an additional heat treatment (400°C) and thermal shocks: cold – heat (difference 270°C) and heat – cold (difference 170°C) were added to the production.

To increase the efficiency of rejecting defective pieces under thermal control and to decrease the heat-treatment duration, we studied variations in time of the degree of hardening and mechanical strength of prehardened samples at specified temperatures.

The experiments were performed in a muffle furnace. The specified temperature was measured by a potentiometer, the duration was monitored by a stopwatch, the variation in the degree of hardening was determined using a quartz wedge, and the bending strength was determined on a PGL-5 hydraulic press.

After the mathematical processing of data obtained, the dependences of the variation in time of the degree of hardening (based on the variation Δ of the number of pores per 1 cm) and bending strength (the ratio of strength after hardening to initial strength $\overline{R}_t/\overline{R}_0$) were plotted (Fig. 3) and then used to determine the optimum temperature and time parameters of thermal control and thermal treatment. This made it possible to ensure a relaxation of hardening stresses not more than 10% and a more effective rejection of insulator parts that have extraneous microinclusions under a positive thermal shock and parts with weak asymmetric hardening under a negative thermal shock. In this method there is no risk of high-quality insulator parts acquiring defects under thermal control, since the total tensile load under positive and negative thermal shocks does not exceed the asymptotic strength of hardened glass.

The use of the proposed parameters has made it possible to increase the efficiency of rejection by extending the temperature difference from 270 to 370°C, to shorten the time of thermal treatment, and to decrease the length of the thermal control furnace by 50%.

Theses technical solutions have been implemented in production on LVI-7 machine line at the Lvov Insulator Works, which has improved the reliability of glass insulator parts for high-voltage insulators.

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